Motor-Manipulatory Behaviours and Learning: An Observational Study

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***Abstract*—In this paper we investigated the role of motor-manipulatory behaviour in the learning modalities of thirty-five primary school children interacting with a Lego MindStorms kit. In particular, by means of an observational taxonomy of children's behaviour, we analysed the video records of two observational sessions regarding the learning activities during the building of a small robot. Our results demonstrated that motor-manipulatory behaviours are strictly linked to cognitive processes, and that the acquisition of new knowledge can be considered as the result of a gradual experience of integration between both perceptual and manipulative behavioural routines.**

***Index Terms*—Robots, cognitive science, children, observability, materials handling.**

I. INTRODUCTION

Over recent decades, numerous researchers have considered learning to be the result of a process of acquisition and construction of knowledge, through the observation of the effects of actions in the world [22; 28; 29; 31]. In particular, the constructivist approach has studied the use of tools in educational contexts and investigated the cognitive activity of human subjects considering the artifacts that mediate it [5; 16; 26; 27; 33]. In the educational context a revolution has taken place: in few years technological development has promoted the reformulation of the relationship between learning and manipulation by the design of new tools to support didactics [8; 9; 15; 17; 21], so that sophisticated tools have replaced the traditional paper materials (books, notebooks, and so on). A number of these tools that have revaluated the great importance of manipulation and its influence on the teaching/learning process [3] were "robot construction kits", built in accordance with the educational principles derived from Piaget's theories [31]. Multidisciplinary Robotics has offered a special educational leverage involving many technical topics, including algebra and trigonometry, design and innovation, electronics and programming, forces and laws of motion, materials and physical processes [18]. In this view, researchers have considered it as a particularly motivating technology, able to stimulate the learning of concepts and methods related to the education of students in scientific fields [2; 7; 20; 23; 24; 32] with a whole literature devoted just to using Lego MindStorms kit [6; 10; 11; 19; 25; 30], at levels ranging from primary school to University [1; 4; 12; 13; 14;]. However, among the current formal studies on the use of robots with pre-college students [3; 8; 9], the scientific observation of subjects as they build their Lego robots is still in its infancy, even if these studies could provide "insight into student thinking and link that thinking to the experiences that triggered the thinking" [30]. In the research here presented, we have built an observational taxonomy of primary school children's behaviour in order to investigate the critical role of manipulation in their learning modalities with a Robotic Lego MindStorms kit. Our hypothesis was that manipulation is critical for the acquisition of knowledge and for the comprehension of the task: the more children manipulate and explore a tool, the more they are able to acquire skills regarding it. In particular, in the first phase of the research, children attended an eight hour course of theoretical lessons about Robotics; in the second phase subjects were randomly divided in groups, and each group was video recorded during the building of a very simple robot. This first observational session was used as a pilot study to identify the behavioural categories of the taxonomy. In the third phase, the children programmed the behaviour of the robots, and in the fourth phase built a complex robot. In section 2, we show the method adopted for the research and the elaborated taxonomy; in section 3, we analyze the results. Finally, in section 4 we have discussion and conclusions.

II. METHODOLOGY

A. Subjects

The sample consisted of thirty-five participants (nineteen girls and sixteen boys), 10 years-old children not familiar with the concepts of Educational Robotics or the Lego MindStorms kit, attending two different classes of a 4th year in a primary school. In the second phase of the research participants were randomly divided in 8 groups, 5 of 4 children and 3 groups of 5.

The experiment was carried out in the structured context of the educative environment to which the children belonged, in a delimitated specific area.

B. Materials

The materials included: a) the Lego MindStorms kit, consisting of more than 700 pieces (Figure 1), a micro-computer called RCX (Robotics Command System), infrared transmitters, light and touch sensors, motors, gears, the RIS (Robotics Invention System) software to program the RCX, and the building guide "Constructopedia"; b) a Panasonic MS1 HQ video camera to record children's activities; c) a BR-S811E Editing Recorder to analyse the videotapes.

Figure 1. An example of Lego MindStorms System pieces.

C. Procedure

The research lasted 7 months and it was carried out in 4 phases. In the first phase researchers familiarized with children in their classes, introduced by their teachers, and submitted a questionnaire about children's previous skills regarding Lego MindStorms kit, traditional Lego bricks, and computers. Furthermore, the classes attended an eight hours course of theoretical lessons about Robotics, aiming at the building of an autonomous robot, and learning the basis concepts of the cognitive behaviour.

In the second phase (observational session) subjects were randomly divided in groups, and each group was video recorded during the building of a very simple robot; in the third phase children programmed the behaviour of the robots. Finally, in the fourth phase of the research (observational session), each group built a complex robot, endowed with light and touch sensors, and able to perform a complex behaviour, such as avoiding obstacles, reaching a location, responding to particular stimuli coming from the environment. Each observational session lasted 3 hours.

Before starting the coding sessions of the videotapes using the Editing Recorder, we realized a reliability check procedure for synchronizing behavioural categories: four coders blind to the main hypothesis of the research observed randomly selected extracts of the videotapes regarding both the observational sessions (total duration: 15 minutes), and the collected data were elaborated by ComKappa software, obtaining the following indexes of agreement: 0.65 for the first session and 0.70 for the second one. Then coders analysed videotapes (total duration: six hours), inserting the observed behaviour in a check-list every time it has been performed (behaviour sampling), indicating its duration.

D. Taxonomy

We elaborated the taxonomy (Table 1) using the first observational session as a pilot study to individuate the following behavioural macro and micro-categories:

(1) Perceptual. Subjects do not manipulate the pieces of the Lego MindStorms kit, but examine them only through observation, aiming at the acquisition of a general knowledge of the objects.

(2) Motor-Manipulatory. Subjects manipulate the pieces of the kit; this behaviour is divided in:

   a. Exploratory. Subjects manipulate the pieces of the kit to determine their precise characteristics, i.e. "a lift arm".

   b. Object-Oriented. Subjects manipulate the pieces of the kit aiming at a particular goal, i.e. the search of a specific piece.

   c. Combinatorial. Subjects manipulate the pieces of the kit to test different possibilities in combinatorial actions, i.e. a subject connects a yellow brick to a gear.

(3) Functional-Conceptual. Subjects manipulate the pieces of the kit, checking the functionality of their work, i.e. a subject tests if the wheels allow the motion of the robot.

TABLE I.
THE OBSERVATIONAL TAXONOMY

Perceptual behaviours
To look at the pieces To read the instruction
Motor-Manipulator behaviours
Exploratory behaviours
To search among the pieces To look for a piece To take a piece
Object-Oriented behaviours
To indicate a piece To give a piece to someone To choose a piece To manipulate the pieces
Combinatorial behaviours
To compare a piece to another To connect two pieces To disassemble two pieces To test a connection of pieces To connect pieces creating a functional unit
Functional-Conceptual Behaviours
To attribute a new functionality to a piece To test a functional unit

An example of check list is present in Figure 2.

Subject:															**Class:**												
Observer:															**Duration:**												
Exploratory	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
To search among the pieces																											
To look for a piece																											
To take a piece																											

Figure 2. An example of the check list used for the observation of Motor-Manipulatory Behaviours (micro-category: Exploratory Behaviours).

III. RESULTS

We checked the frequency of motor-manipulatory behaviours in both the observational sessions by an ANOVA: we divided the average frequencies regarding all the behaviours for the average duration of each behaviour. This calculation was executed for each participant and entered into a One-Way ANOVA within groups (perceptual, exploratory, object-oriented, combinatorial, functional-conceptual behaviours). In the first session, the effect was significant, $F(4, 170)=34.91$, $MSE=70.00$, $p< .001$. The result shows that motor-manipulatory behaviour ($M=55.09$, $SD =15.09$) is more frequent than both perceptual ($M=22.00$, $SD=6.26$) and functional-conceptual one ($M=17.15$, $SD=13.37$) (post-hoc Newman-Keuls, $p< .001$). In the second session, the effect was also significant, $F(4, 170)=28.21$, $MSE=5.21$, p<.001, and the motor-manipulatory behaviour (M=13.02, SD=4.73) resulted more frequent than both perceptual (M=5.11, SD=1.70) and functional-conceptual one (M=4.52, SD=1.23) (post-hoc Newman-Keuls, p<.001). Error bars indicate a standard error of the mean (Figure 3).

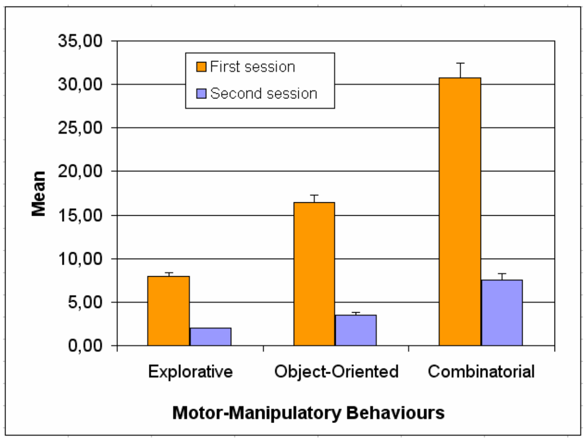

Figure 3. The mean of the perceptual, motor-manipulatory and functional-conceptual behaviours in both the observational sessions. Error bars indicate a standard error of the mean.

Afterwards, we checked the frequency of behaviours in exploratory, object-oriented, combinatorial behaviours, in both the observational sessions, by a One-Way ANOVA within groups. In the first session the effect was significant, F(2, 102)=105.87, MSE=43.93, p< .001. The more representative behaviours in terms of frequency and duration were combinatorial ones (M=30.74, SD=10.08), designating combinatorial behaviour as the most frequent motor-manipulatory behaviour. In the second session, a One-Way ANOVA within groups showed also combinatorial behaviours as the most representative in terms of frequency and duration (M=7.51, SD=4.36). Error bars indicate a standard error of the mean (Figure 4).

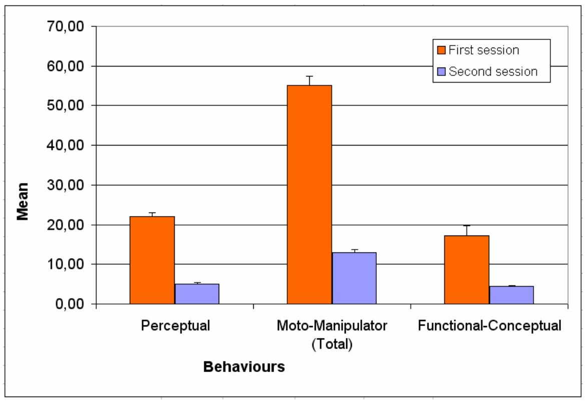

Figure 4. The mean of the exploratory, object-oriented and combinatorial behaviours in both the observational sessions. Error bars indicate a standard error of the mean.

Then we carried out a correlation analysis to investigate the relationship among the functional-conceptual and the others behaviours (perceptual and motor-manipulatory). Results showed a strongest correlation between motor-manipulatory and functional-conceptual behaviours, in comparison to the correlation between perceptual and functional-conceptual ones. In fact, in the first observational session, the correlation coefficient r between perceptual and functional-conceptual behaviours is -0.29 (Figure 5), while between motor-manipulatory and functional-conceptual behaviours is 0.59 (Figure 6).

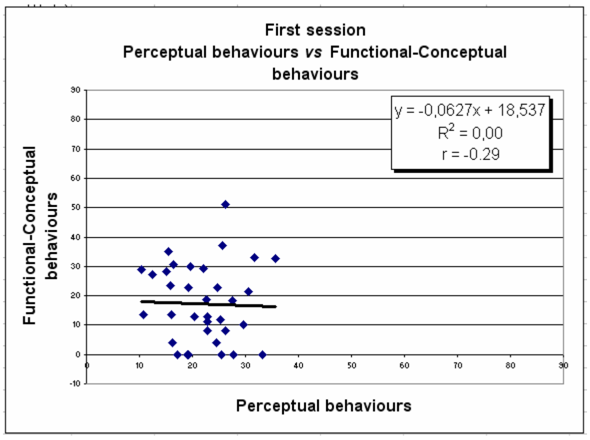

Figure 5. The correlation between perceptual and functional-conceptual behaviours in the first session.

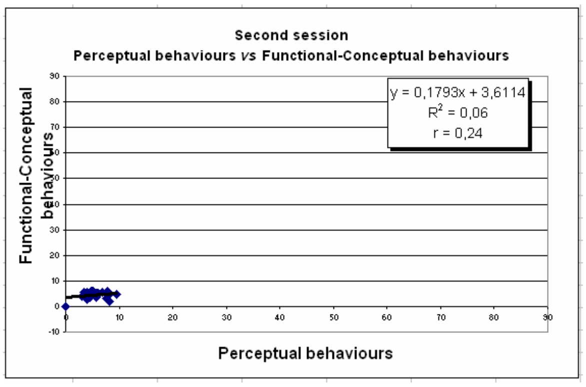

Figure 6. The correlation between perceptual and functional-conceptual behaviours in the second session.

In the second session, the correlation coefficient *r* between perceptual and functional-conceptual behaviours is 0.24 (Figure 9), while between motor-manipulatory and functional-conceptual behaviours is 0.38 (Figure 10).

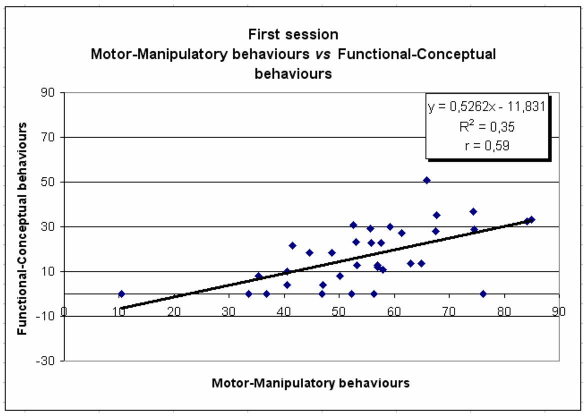

Figure 7. The correlation between motor-manipulatory and functional-conceptual behaviours in the first session..

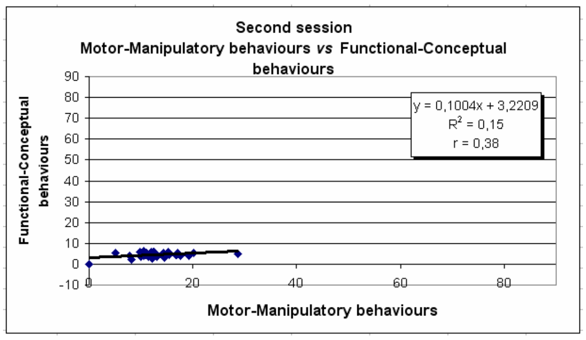

Figure 8. The correlation between motor-manipolatory and functional-conceptual behaviours in the second session.

IV. CONCLUSIONS

Our observational study demonstrated that firstly children observe tools to acquire a general information about them; then they conduct a long process of exploration through a repeated manipulation of the objects (this process has a major frequency and duration with respect to both perceptual and functional behaviours), reiterating this routine. Therefore, according the results of our research, the acquisition of new knowledge (the use of pieces and tools for the realization of a complex robotic agent) can be considered as the result of a gradual experience of integration between both perceptual and manipulative behavioural routines. Furthermore, if children are involved in a task of building, they prefer combinatorial behaviours.

In conclusion, motor-manipulatory behaviours contribute not only to increase the individual perception of the object properties, but to acquire a deeper understanding of the object itself. Knowledge is anchored in experience and it can not be separated from action. These results are in line with other experimental results indicating that knowledge and comprehension are grounded in action, and in particular in manipulation.

REFERENCES

[1] A. Arcella, P.A. Bertacchini, E. Bilotta and L. Gabriele, Progettare il comportamento di un robot: un esperimento didattico, in P.A. Bertacchini, E. Bilotta, S. Nolfi and P. Pantano (eds.), *Proceedings of the first Italian workshop of artificial life*, Arcavacata di Rende, Cosenza, Italy, 2003.

[2] R.D. Beer, H.J. Chiel and R.F. Drushel, Using autonomous robots to teach science and engineering, *Communications of the ACM*, vol. 42, pp. 85–92, 1999.

[3] P.A. Bertacchini, E. Bilotta, L. Gabriele, P. Pantano and R. Servidio, *Apprendere con le mani, Strategie cognitive per la realizzazione di ambienti di apprendimento-insegnamento con i nuovi strumenti tecnologici*, FrancoAngeli Editore, 2006.

[4] P.A. Bertacchini, E. Bilotta, L. Gabriele, P. Pantano, P. and Servidio, R.: Investigating cognitive processes in robotic programmers developed by children in educational context, in M Roccetti, & MR Syed (eds.), Proceedings of international conference on simulation and multimedia in engineering education/Western multiconference on computer simulation (ICSEE/WMC '03), SCS, Orlando, pp. 111-116, 2003.

[5] P.A. Bertacchini, E. Bilotta, L. Gabriele, A. Tavernise and R. Servidio, Investigating learning processes through educational robotics, *ASLA Online II conference* - May 2006.

[6] A. Billard and A. Robota: Clever toy and educational tool, Robotics and Autonomous Systems, Vol. 42, Issue 3-4, March 31, pp. 259-269, 2003.

[7] E. Bilotta, A colloquio con ricercatori che hanno cambiato il modo di fare didattica, *Onde - Rivista di Comunicazione e Informazione, Numero speciale: Tecnologie Educative*, Abramo Editore, Vol. 1 (1), pp. 7-9, 2001.

[8] E. Bilotta, L. Gabriele, P. Pantano and R. Servidio, Robot, Bambini e apprendimento, *Congresso Nazionale della Sezione di Psicologia Sperimentale dell'AIP*, Bellaria-Rimini, 16-18 Settembre 2002.

[9] E. Bilotta, L. Gabriele and R. Servidio, Robotica e Creatività: una ricerca empirica in bambini di scuola elementare, *Quaderni del Centro Interdipartimentale della Comunicazione*, 10, UNICAL, Cosenza, 2001.

[10] P. Capozzoli and C. Rogers, Legos and aeronautics in kindergarten through college, paper presented at the *Advanced Measurement and Ground Testing Technology Conference*, New Orleans, LA, 1996.

[11] B. Denis and S. Hubert, Collaborative learning in an educational robotics environment, *Computers in Human Behavior* Vol. 17, Issue 5-6, September - November, 2001, pp. 465-480, 2001.

[12] A. Druin, The new robotics: the educators' challenge, in A Druin, & J Hendler (eds.), *Robots for kids: exploring new technologies for learning*, Morgan Kaufman/Academic Press, San Francisco, pp. 158–164, 2000.

[13] L. Gabriele, R. Servidio and A. Tavernise, Acquisire concetti complessi attraverso l'uso di strumenti: un'indagine empirica, *Atti del Congresso Nazionale della Sezione di Psicologia Sperimentale dell'AIP - Associazione Italiana di Psicologia*, Cagliari, 18-20 settembre 2005.

[14] L. Gabriele, A. Arcella, R. Servidio and P.A. Bertacchini, Investigare strategie di problem solving attraverso la robotica: un'esperienza con studenti universitari". *Atti del convegno "2° Workshop Italiano di Vita Artificiale*", Istituto di Scienze e Tecnologie della Cognizione, CNR, Roma, 2-5 Marzo, 2005, A cura di Baldassarre G., Marocco D., Mirolli M., CNR:Roma, 2005.

[15] R. Goldman, M.Q. Azhar and E. Sklar, From RoboLab to Aibo: A Behavior-based Interface for Educational Robotics, in *Proceedings of RoboCup-2006: Robot Soccer World Cup X*, 2006.

[16] E. Hutchins, *Cognition in the wild*, MIT Press, Cambridge, MA, 1995.

[17] M. Jadud, Teamstorms as a theory of instruction, in *Proceedings of IEEE Systems, Cybernetics, and Man 2000* (SMC2000).

[18] J. Johnson, Children, robotics, and education, in *Proceedings of the 7th International Symposium on Artificial Life and Robotics* (AROB-7), pp. 491–496, 2002.

[19] F. Klassner and S. Anderson, Lego MindStorms: Not just for K-12 anymore. *IEEE Robotics and Automation Magazine*, 2003.

[20] D. Kumar and L. Meedan, A robot laboratory for teaching artificial intelligence, in J Daniel (ed.), *Proceedings of the 1998 ACM SIGCSE symposium, ACM Press*, New York, pp. 341–344, 1998.

[21] H.H. Lund, T. Klitbo and C. Jessen, Playware Technology for Physically Activating Play, *Artificial life and Robotics*, vol. 9 (4), pp. 165-174, Springer Japan, 2005.

[22] F. Martin, *Circuits to Control: Learning Engineering by Designing LEGO Robots*, Ph. D. Thesis. MIT, Boston, 1994.

[23] F. Martin, B. Mikhak, M. Resnick, B. Silverman and R. Berg, To Mindstorms and Beyond. Evolution of a Construction Kit for Magical Machine, in Druin, A.; Hendler, J. (Eds), *Robots for kids: Exploring New Technologies for Learning*. San Francisco: Morgan Kaufman/Accademic Press, 2000.

[24] O. Miglino, H.H. Lund and M. Cardaci, Robotics as an educational tool, *Journal of Interactive Learning Research*, vol. 10, no. 1, pp. 25–48, 1999.

[25] A. Nagchaudhuri, G. Singh, M. Kaur and S. George, Lego robotics products boost student creativity in pre-college programs at UMES, in D. Budny, and G. Bjedov. (eds.), *Proceedings of 32nd ASEE/IEEE frontiers in education conference, IEEE*, Piscataway, pp. S4D-1–S4D-6, 2002.

[26] D.A. Norman, Cognitive artefacts, in J. Carroll (ed.), *Designing interaction: psychology at the human-computer interface*, Cambridge University Press, 1991

[27] D.A. Norman, *Things that make us smart*, Addison-Wesley, New York, 1993.

[28] S. Papert, *Mindstorms, bambini computers e creatività*, Emme edizioni, Milano, 1984.

[29] S. Papert and I. Harel, *Constructionism*, Ablex Publishing, Norwood, 1991.

[30] M.B. Petre, B. Price, Using Robotics to Motivate 'Back Door' Learning, *Education and Information Technologies* 9:2, 2004.

[31] J. Piaget and B. Inhelder, *La psicologia del bambino*, Einaudi, Torino, 1970.

[32] J. B. Weinberg, G.L. Engel, K. Gu, C.S. Karacal, S.R. Smith, W.W. White and X.W. Yu, A multidisciplinary model for using robotics in engineering education. In *Proceedings of the 2001 ASEE Annual Conference and Exposition*, 2001.

[33] J. Zhang and D.A. Norman, A representation analysis of numeration systems, *Cognition*, vol. 57, pp. 271–295, 1995.

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